Final Baseline Human Health and Ecological Risk Assessment

Lower Fox River and Green Bay, Wisconsin Remedial Investigation and Feasibility Study

Prepared for:

Wisconsin Dept. of Natural Resources

Prepared by: The RETEC Group, Inc.

December 2002

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EXECUTIVE SUMMARY

A *Baseline Human Health and Ecological Risk Assessment for the Lower Fox River and Green Bay* (BLRA) has been prepared as a companion document to the Remedial Investigation (RI) and Feasibility Study (FS). This section summarizes the baseline risks to human health for the Lower Fox River and Green Bay, and the calculation of sediment quality thresholds (SQTs) that support the selection of a remedy which eliminates, reduces, and/or controls risks identified in the human health and ecological assessments. The SQTs themselves are not cleanup criteria, but are a good approximation of protective sediment values and can be considered to be "working values" from which to select a remedial action level.

This RI/FS report is consistent with the findings of the National Academy of Science's National Research Council Report entitled, *A Risk Management Strategy for PCB Contaminated Sediments* (NRC, 2001).

The overall goals of the BLRA for the Lower Fox River and Green Bay were to:

- Examine how the contaminants of potential concern (COPCs) carried forward from the Screening Level Risk Assessment (SLRA) (RETEC, 1998b) move from the sediment and water into human and ecological receptors within the Lower Fox River and Green Bay.
- Quantify the current (or baseline) human health and ecological risk associated with the COPCs.
- Distinguish those COPCs which pose the greatest potential for risk to human health and the environment and should be carried forward as contaminants of concern (COCs) in the FS.
- Determine which exposure pathways lead to the greatest risks.
- Support the selection of a remedy which eliminates, reduces, and/or controls identified risks by calculating sediment quality thresholds (SQTs).

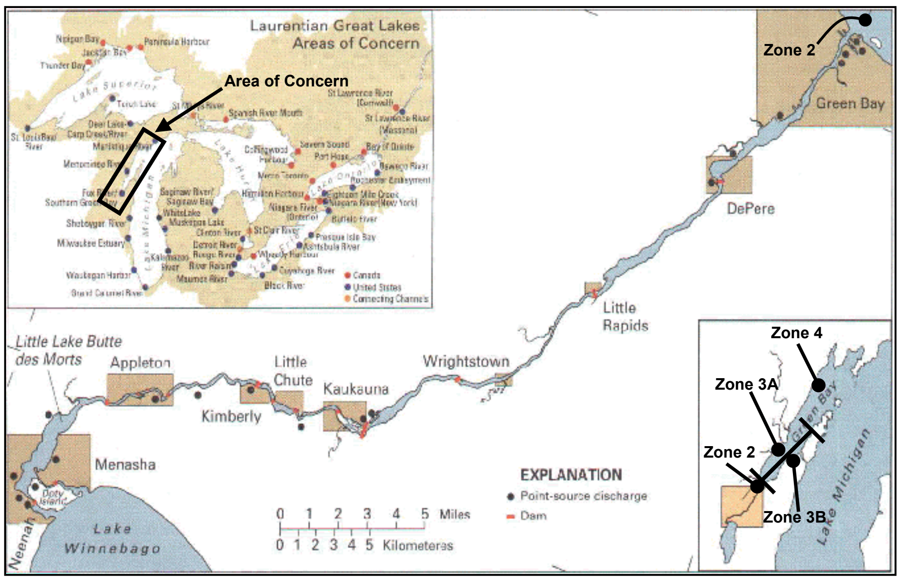


Figure 1 Risk Assessment Study Areas

Site Description

Between 1954 and 1971, paper mills in the Lower Fox River valley manufactured and recycled carbonless copy paper that contained PCBs, resulting in the release of an estimated 313,600 kg (691,370 pounds) of PCBs in the river. It is estimated that 70 percent of the total PCB mass in the river has been transported into Green Bay. Sediment from the Lower Fox River is primarily deposited on the southeastern edge of the bay.

The Fox River valley and Green Bay area is diverse in terms of land use, population density, and habitat types. Overall, the shoreline is much more developed and populated along the Lower Fox River as compared to Green Bay. Both the human health and ecological risk assessments focused on aquatic-dependent receptors and Green Bay has historically supported strong commercial and sport fishing.

For both the human health and ecological assessments, risk was characterized for the four reaches of the Lower Fox River: Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (Green Bay Zone 1); as well as the zones of the bay: Zone 2, Zone 3A, Zone 3B, and Zone 4 (Figure 1). Therefore, risks between each of these reaches and zones could be compared.

Data Evaluated

The COPCs carried forward from the SLRA included polychlorinated biphenyls (PCBs) (total and selected congeners), dioxins and furan congeners, dichlorodiphenyltrichloroethane (DDT) and its metabolites (4,4'-dichlorodiphenyltrichloroethane [DDE] and 4,4'-dichlorodiphenyldichloroethane [DDD]), dieldrin, and three metals (arsenic, lead, and mercury). In the SLRA, hazard quotients (HQs) calculated for PCBs were at least an order of magnitude greater than the HQs for any of the other COPCs. HQs are the ratios of measured COPC concentrations in media (water, sediment, tissue) as compared to safe COPC concentrations in these media.

All available electronic data collected from Lake Winnebago to northern Green Bay were compiled into a single database—the Fox River Database (FRDB). This database contains 474,218 records of sediment, water, and tissue data from the early 1970s through the late 1990s. For the assessment of baseline risk in the Lower Fox River and Green Bay, a subset of the data contained in the FRDB was evaluated. Data were included based on the specific receptors selected, the time during which the data were collected, and the COPCs of interest.

A time trend analysis of fish tissue data indicates that while PCB concentrations in fish tissue initially significantly decreased, since the mid 1980s changes in these concentrations have either slowed, remained constant, or have resulted in increased tissue concentrations. For this reason, only fish tissue concentrations from 1989 and after were considered for the ecological risk evaluation and the focused human health risk evaluation.

Similarly, for risk evaluation purposes, the concentration of total PCBs in the top 10 cm (4 inches) of sediment was interpolated, because this is the depth of sediment that is of primary biological activity. The degree of biological activity influences the potential for bioaccumulative compounds to be taken up in the food chain. PCB concentrations in sediment were interpolated both horizontally and vertically, but for comparative risk purposes non-interpolated sediment PCB concentrations were also evaluated for risk.

General Conclusions

General conclusions of both the human health and ecological assessments were that:

- Fish consumption is the exposure pathway that represents the greatest level of risk for receptors (other than direct risk to benthic invertebrates).

- The primary COC is PCBs, and other COCs carried forward for remedial evaluation and long-term monitoring are mercury and DDE.
- In general, areas evaluated with the greatest risk are Green Bay zones 1 and 2.

Human Health Risk Assessment

For the human health risk assessment, two evaluations were performed, a baseline risk assessment and a focused risk assessment, which are described shortly. For the baseline risk assessment, all data for a specific medium for each COPC were used to evaluate exposures and risks. For the focused risk assessment, which examined only exposure to PCBs in fish, only fish tissue data from 1989 and after were used.

Receptors evaluated in the human health risk assessment were:

- Recreational anglers,
- High-intake fish consumers,
- Hunters,
- Drinking water users,
- Local residents,
- Recreational water users (swimmers and waders), and
- Marine construction workers.

The principle findings of the human health risk assessment are:

- Consumption of fish from the Lower Fox River and Green Bay presented the highest cancer risks and noncancer hazard indices for the pathways evaluated which also included those associated with consumption of waterfowl, drinking water, breathing air near the river or bay, swimming, and construction in the river or bay.
- PCBs contribute more than 70 percent of the cancer risks found from the consumption of fish and waterfowl.
- Using fish data since 1989, lifetime cancer risks as great as one in 1,000 were found for recreational anglers and high-intake fish consumers exposed to PCBs. High-intake fish consumers are individuals in the recreational angler population who may eat significantly more fish than recreational anglers. Groups within the high-intake fish consumer category that were explicitly evaluated in this risk assessment were low-income minority anglers, Hmong/Laotian anglers, and Native American anglers.
- While high-intake fish consumers are individuals who may eat significantly more fish than typical recreational anglers, there were not large differences in risks between recreational anglers and high-intake fish consumers for the high fish consumption or reasonable maximum exposure scenarios.
- Cancer risks from fish consumption are 1,000 times greater than the one-in-a-million cancer risk, which is the point at which risk management decisions may be made under Superfund. The cancer risks are 100 times greater than the one-in-a-hundred-thousand lifetime cancer risk

used by Wisconsin for evaluating hazardous waste sites.

- Noncancer hazard indices from fish consumption were as much as 50 times greater than levels considered acceptable for exposures ranging from 7 years to a lifetime. The noncancer health effects associated with exposure to PCBs include developmental effects (e.g., neurological impairment in infants and children due to maternal exposure), reproductive effects (e.g., conceptive failure), and immune system suppression (e.g., increased incidence of infectious disease in infants).

- Noncancer hazard indices were also calculated for young children eating fish for the Little Lake Butte des Morts and De Pere to Green Bay reaches, the two reaches with the greatest population density. The hazard indices were approximately 2.4 times those found for adults or as much as 125 times greater than acceptable levels.

- Populations potentially exposed to PCBs via fish consumption are large. There are 136,000 fishing licenses issued to individuals living in counties adjacent to the Lower Fox River and Green Bay. About 10 percent of this angler population, or about 14,000 persons, would be considered high-intake anglers. These populations are potentially exposed to PCBs at levels associated with adverse health consequences.

- Cancer risks and noncancer hazard indices are more than 20 times greater than those from the consumption of fish from Lake Winnebago, which does not

Table 1 Summary of Human Health Risks

Location	Recreational Angler		High Intake Fish Consumer		Hunter		Drinking Water User		Local Resident		Swimmer		Wader		Marine Construction Worker	
	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index	Cancer Risk	Noncancer Hazard Index
Little Lake Butte des Morts	$>10^{-4}$	>25	$>10^{-4}$	>35	10^{-6}--10^{-4}	~1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$\sim10^{-6}$	<1
Appleton to Little Rapids	$>10^{-4}$	>20	$>10^{-4}$	>30	10^{-6}--10^{-4}	~1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1
Little Rapids to De Pere	$>10^{-4}$	>15	$>10^{-4}$	>20	10^{-6}--10^{-4}	~1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1
De Pere to GreenBay	$>10^{-4}$	>35	$>10^{-4}$	>50	10^{-6}--10^{-4}	~1	10^{-6}--10^{-4}	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1
Zone 3A	$>10^{-4}$	>25	$>10^{-4}$	>50												
Zone 3B	$>10^{-4}$	>25	$>10^{-4}$	>35	10^{-6}--10^{-4}	~1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1	$<10^{-6}$	<1
Zone 4	$>10^{-4}$	>25	$>10^{-4}$	>35												

Notes:

Risks and hazard indices are based on reasonable maximum exposures.

Interpretation of cancer risks:

$> 10^{-4}$ indicates significant risk

10^{-6}--10^{-4} indicates possibly significant risks

$<10^{-6}$ indicates risks are negligible

Interpretation of hazard indices:

>1 indicates significant noncancer health effects are possible

<1 indicates noncancer health effects are unlikely to be significant

For recreational anglers, high intake fish consumers and hunters, elevated risks and hazard indices are due primarily to PCBs.

For drinking water users in De Pere to Green Bay reach, arsenic is responsible for caculated cancer risk, but arsenic exposure point concentration was based on one detected value in four samples and reporting limits were high, so actual arsenic concentrat have a known source of PCBs and serves as a background location.

- There were not large differences in risks between the Lower Fox River and Green Bay, or among the reaches within the Lower Fox River, or among the zones within Green Bay.

- While evidence exists for slow declines of PCBs in fish, such declines were not consistent among species or locations, and projections of future declines cannot be made with sufficient certainty for use in risk assessment. In addition, in some cases, PCBs were found to be increasing.

Other findings of the human health risk assessment are:

- Cancer risks to hunters consuming waterfowl approach a risk of one in 10,000. Noncancer hazard indices were 3.8 times acceptable levels.

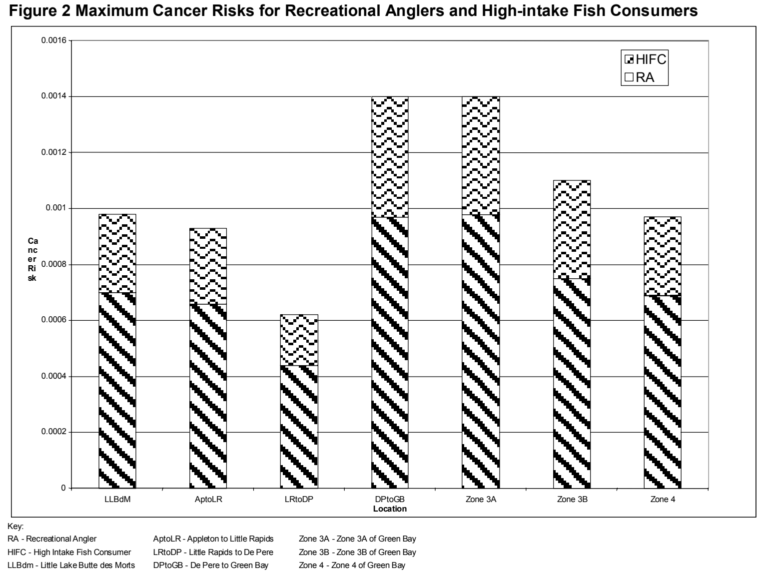
- Cancer risks to local residents exposed to chemicals only through inhalation of air, swimmers, and waders were less than one in a million.

- Cancer risks to drinking water users were less than one in a million in all reaches of the Lower Fox River and all of Green Bay with one exception. The cancer risk in the De Pere to Green Bay Reach was 3.8×10^{-5} due to exposure to arsenic. The arsenic and the exposure to arsenic were based on the detection of this chemical in one of four surface water samples. It is quite likely that this one detected value is anomalous and that the actual risk of exposure to arsenic is much lower. In addition, this reach of the Lower Fox River is not used as a source of drinking water.

- Marine construction workers had cancer risks slightly greater than one in a million. Noncancer hazard indices for drinking water users, local residents, swimmers, waders, and marine construction workers did not exceed acceptable levels.

These results are summarized in Table 1. Figure 2 presents the risks and Figure 3 presents the hazard indices for recreational anglers and high-intake fish consumers due to ingestion of PCBs in fish.

Figure 2 Maximum Cancer Risks for Recreational Anglers and High-intake Fish Consumers



Ecological Risk Assessment

Types of receptors evaluated for ecological risk included:

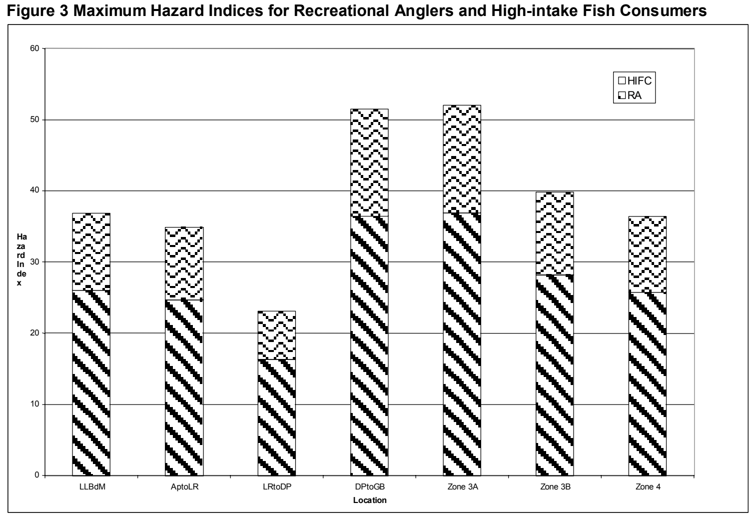
- **Aquatic Invertebrates:** Insects and other invertebrates that live in the water and are important prey items for fish and other insects.

- **Benthic Invertebrates:** Insects and other invertebrates that live in or on the sediment that are important in recycling nutrients and are a principal part of fish diets.

- **Benthic Fish:** Fish, such as carp and catfish, that live on and forage in the sediments and are in turn eaten by other fish, birds, mammals, and people.
- **Pelagic Fish:** Fish, such as walleye and yellow perch, that live in the water column, and eat other fish or insects that live in the water or on the sediments. These fish may be in turn eaten by other fish, birds, mammals, and people.
- **Insectivorous Birds:** Birds, such as swallows, that eat insects that hatch from the sediments.
- **Piscivorous Birds:** Birds, such as cormorants or terns, that principally eat fish from the Lower Fox River or Green Bay.
- **Carnivorous Birds:** Birds, such as eagles, that eat a variety of prey, including fish or small mammals.
- **Piscivorous Mammals:** Mammals, such as mink, that eat fish as an important part of their diet.

Risk was characterized for assessment endpoints based on the calculation of HQs. In the FRDB, data were generally lacking for piscivorous and carnivorous birds, and no data were available for piscivorous mammals, therefore, ecological modeling was used to estimate COPC exposure to these receptors. HQs that are greater than 1.0 imply that risk may be present. Where available, both the No Observed Adverse Effect Concentration (NOAEC) and Lowest Observed Adverse Effect Concentration (LOAEC) HQs were calculated. Effects evaluated were reproductive dysfunction, death at birth, or deformities in the surviving offspring. When NOAEC HQs exceeded 1.0, but LOAEC HQs were less than 1.0, then it was concluded that there was potential risk. When both the NOAEC and LOAEC HQs exceed 1.0, it was assumed that risk is present.

Figure 3 Maximum Hazard Indices for Recreational Anglers and High-intake Fish Consumers



Key:
RA - Recreational Angler
HIFC - High Intake Fish Consumer
LLBdm - Little Lake Butte des
AptoLR - Appleton to Little
LRtoDP - Little Rapids to De
DPtoGB - De Pere to Green
Zone 3A - Zone 3A of Green Bay
Zone 3B - Zone 3B of Green Bay
Zone 4 - Zone 4 of Green Bay

In addition to the HQ, the assessment provides an evaluation of the uncertainties associated with the risk characterization, and evaluates the estimated risk relative to the habitat, field studies, and population data for the receptors species. Together with the HQs, the components of the evaluation provide resource managers with the information necessary to make risk decisions within the context of the Feasibility Study.

The principle findings of the ecological risk assessment are:

- Total PCBs cause, or potentially cause risk to all identified receptors. The exception is insectivorous birds where the weight of evidence suggests that these receptors are not at risk from PCB concentrations. Not all receptors at risk or potentially at risk from PCBs are at risk in all river reaches or bay zones.

- Mercury poses a risk in all river reaches and zones, but not to all receptors. Mercury was not identified as a risk for benthic fish, insectivorous birds, or piscivorous mammals.

- DDT or its metabolites poses a risk to benthic invertebrates (Little Lake Butte des Morts Reach, Little Rapids to De Pere Reach, and Green Bay Zone 1), benthic fish (Green Bay zones 1 and 2), pelagic fish (Green Bay zones 1, 2, 3B, and 4), insectivorous birds (Green Bay Zone 2), piscivorous birds (Green Bay zones 1, 2, and 3B), and carnivorous birds (Green Bay zones 1, 2, 3B, and 4).

- Other COPCs identified as causing or potentially causing risk are arsenic (Zone 1 and Zone 3B benthic invertebrates only) lead (benthic invertebrates only in all areas except Green Bay Zone 2, Zone 3A, and Zone 4), 2,3,7,8-TCDD (benthic invertebrates only in Little Lake Butte des Morts Reach and Little Rapids to De Pere Reach), and dieldrin (piscivorous birds in zones 1, 2, and 3B, carnivorous birds in Green Bay Zone 3A, and piscivorous mammals in Green Bay zones 3A and 3B).

Table 2 summarizes ecological risks based on hazard quotients and other lines of evidence. Figures 4 (total PCBs), 5 (mercury), and 6 (DDT and metabolites) present HQs that were greater than 1.0 for selected receptors.

Table 2 Ecological Risk Summary Table

Location	Water Column Invertebrates	Benthic Invertebrates	Benthic Fish	Pelagic Fish	Insectivorous Bird	Piscivorous Bird	Carnivorous Bird	Piscivorous Mammal
LLBdM	● *mercury* ○ *PCBs*	● *lead; mercury; 2,3,7,8-TCDD; PCBs; DDD; DDT*	○ *PCBs*	○ *PCBs*	○ *PCBs*	○ *mercury; PCBs*	○ *PCBs*	● *PCBs*
Appleton to Little Rapids	○ *PCBs*	● *lead; mercury; PCBs*	○ *PCBs*	○ *PCBs*	NA	○ *mercury; PCBs*	● *PCBs* ○ *mercury*	● *PCBs*
Little Rapids to De Pere	● *mercury*	● *lead; mercury; 2,3,7,8-TCDD; PCBs; DDE; DDT*	○ *mercury; PCBs*	○ *mercury; PCBs*	NA	○ *mercury; PCBs*	○ *mercury; PCBs*	● *PCBs*
Zone 1	○ *PCBs*	● *arsenic; lead; mercury; PCBs; DDD; DDE*	○ *PCBs; DDE*	○ *mercury; PCBs; DDE*	○ *PCBs*	○ *mercury; PCBs; dieldrin; DDE*	○ *mercury; PCBs; DDE*	● *PCBs*
Zone 2	● *mercury*	● *mercury; PCBs*			○ *PCBs; DDE*			
Zone 3A		● *PCBs*	○ *PCBs*	○ *PCBs*	NA	○ *mercury; PCBs*	● *PCBs* ○ *dieldrin*	● *PCBs* ○ *dieldrin*
Zone 3B		● *arsenic; lead; mercury; PCBs*		● *PCBs* ○ *mercury; DDE*	NA	● *PCBs* ○ *mercury; dieldrin; DDE*	○ *mercury; PCBs; DDE*	● *PCBs* ○ *dieldrin*
Zone 4		● *PCBs*	NA	○ *PCBs; DDE*	NA	○ *mercury; PCBs*	○ *mercury; PCBs; DDE*	● *PCBs*

Notes:

NA - No data available.

Risk conclusions based on HQs:

(blank box) - No risk

Risk - ●

Potential Risk - ○

Risk conclusions based on weight of evidence:

(yellow) - Site-specific receptor data suggest that there is no risk.

(cyan) - Because of the Federal listing of the bald eagle as threatened, it is concluded that potential risk is actual risk.

Sediment Quality Thresholds (SQTs)

SQTs are sediment concentrations that have been linked to a specific magnitude of risk. SQTs were estimated for PCBs with the assumption that a remedy that reduces PCB exposure would also address the other co-occurring COCs. Risk-based concentrations in fish for human and ecological receptors were determined based on:

- Human health cancer risk levels of 10^{-4}, 10^{-5}, and 10^{-6}, and a noncancer hazard index of 1.0 for risk in recreational anglers and high-intake fish consumers
- The NOAECs and LOAECs for species of benthic invertebrates, fish, birds, and riverine mammals found in the river and bay.

SQTs were developed for each pathway and receptor identified as important in the BLRA by the response agencies of the Lower Fox River and Green Bay (e.g., sport fishing consumption, bald eagles). The SQTs themselves are not cleanup criteria, but are used to evaluate levels of PCBs that will be addressed in the Feasibility Study. The final selection of the remedial action levels is a policy decision left to the response agencies. The development and validation of the mathematical model used to define SQTs is described in the BLRA.

To evaluate how PCBs in sediment result in risk to human or ecological receptors, a methodology is needed for translating concentrations of PCBs in sediment to concentrations in fish and higher order organisms. The Fox River Bioaccumulation Model (FRFood Model) was developed for this purpose. FRFood is a series of mathematical equations that describes a food web and the transfer of bioaccumulating contaminants within that food web. The model includes uptake routes from sediment and water to benthic infauna and ultimately fish, and the model was constructed so that it could be used to either predict fish tissue concentrations from a given sediment concentration, or to predict sediment concentrations from a given fish tissue concentration. The model was validated by running the model "forward;" that is, fish tissue concentrations were predicted from existing sediment concentrations and then compared to measured fish tissue concentrations. When the predicted concentrations were compared to the actual measured concentrations of total PCBs in fish collected in the Lower Fox River and Green Bay, the results were highly comparable.

Estimated SQTs for human health and ecological exposures are shown on Figure 7.

Human Health SQTs

To determine SQTs associated with the protection of human health, fish consumption limits were derived using several different assumptions and risk thresholds. Risk-based fish concentrations (RBFCs) were calculated for recreational anglers and high-intake fish consumers. For recreational anglers, RBFCs were calculated using the average fish intake assumptions from two studies on Michigan anglers (West *et al.*, 1989; West *et al.*, 1993). For high-intake fish consumers, RBFCs were calculated using the average fish intake assumptions for low-income minorities (West *et al.*, 1993) and Hmong (Hutchinson and Kraft, 1994). The RBFCs were generated for each of these exposure scenarios for three different target risk levels (10^{-6}, 10^{-5}, and 10^{-4}) and for a target noncancer hazard index of 1.0. The RBFCs were used with the results of the FRFood Model to generate a range of SQTs.

Deriving SQTs for each of the consumption scenarios and each of the risks and hazard indices resulted in a total of 48 human health SQTs, a minimum SQT of 1.1 µg/kg (carp at a risk level of 10^{-6}, RME for a high-intake fish consumer) and a maximum SQT of 6,770 µg/kg (yellow perch at a risk level of 10^{-4}, CTE for a recreational angler).

Ecological SQTs

SQTs protective of ecological receptors were calculated for the Lower Fox River and Green Bay separately. Although the remedial methods may differ between reaches of the river evaluated, the SQTs derived for the De Pere to Green Bay Reach will be applied to the entire river. These SQTs are based upon levels of total PCBs in fish that either cause risk to the fish themselves, or to birds or mammals that are eating the fish. The SQTs for no observed adverse effects (NOAEC) to walleye is 176, and for carp is

Figure 4 Selected PCB HQs that Exceed 1.0

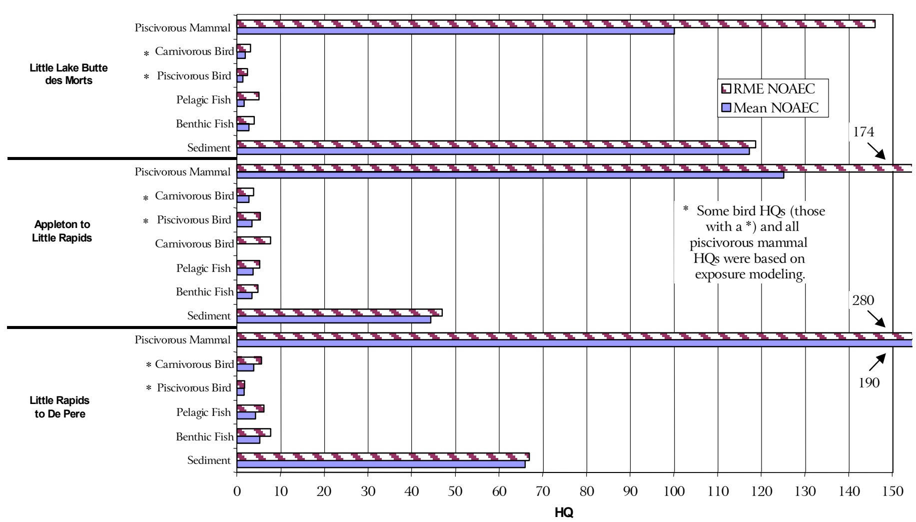
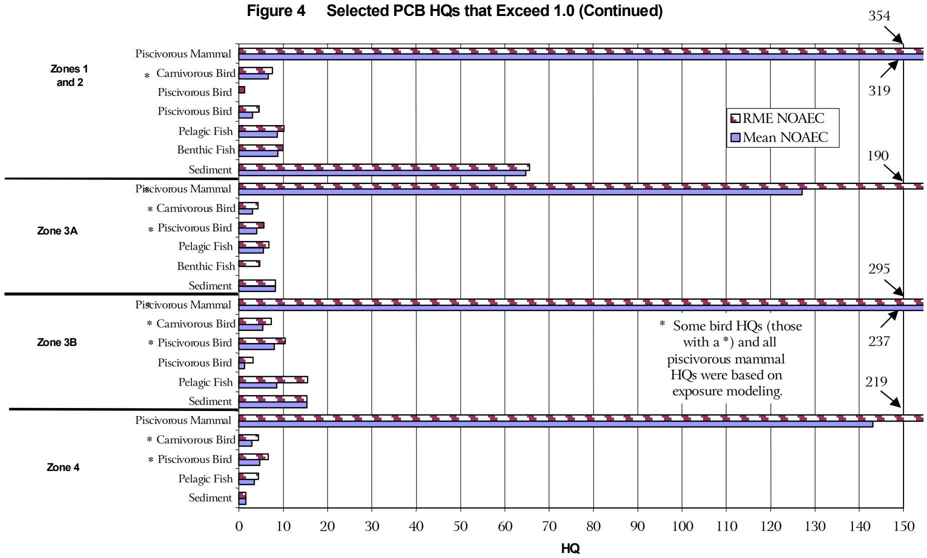


Figure 4 Selected PCB HQs that Exceed 1.0 (Continued)



363. The only calculated SQTs that were lower than these for any of the other receptors were the SQT for benthic invertebrates and the SQTs for piscivorous mammals (mink). The benthic invertebrates threshold effect level (TEL) is a sediment PCB concentration of 31.6 μg/kg and the NOAEC SQT for mink is 24 μg/kg.

Figure 5 Selected Mercury HQs that Exceed 1.0 *

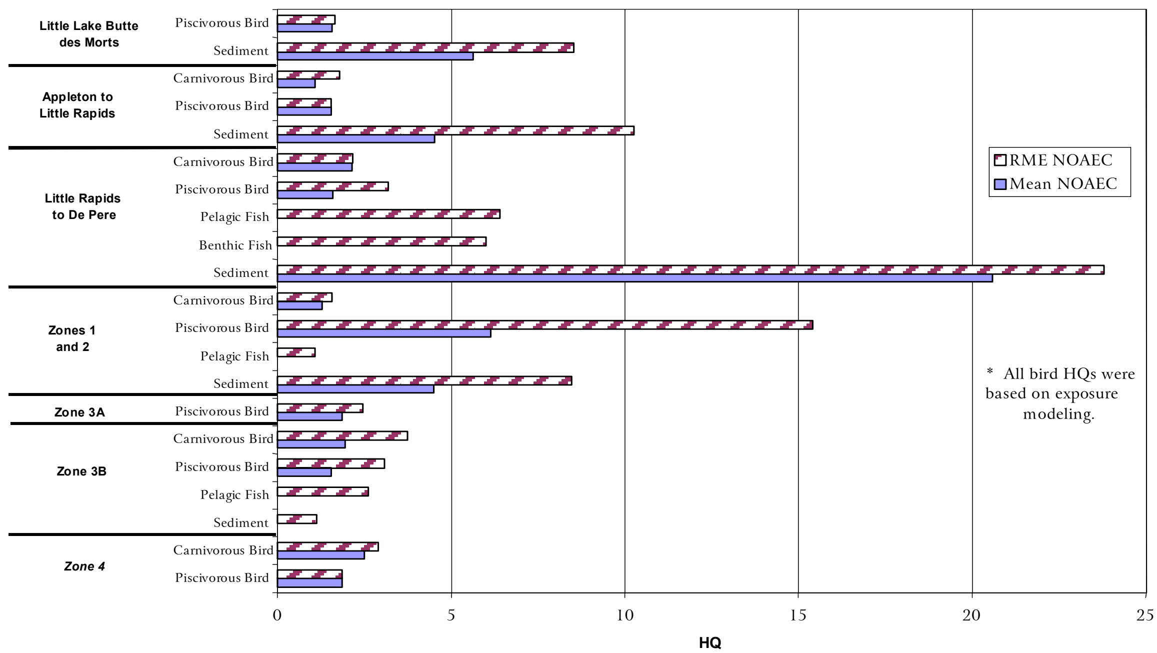


Figure 6 Selected DDT or Metabolite HQs that Exceed 1.0

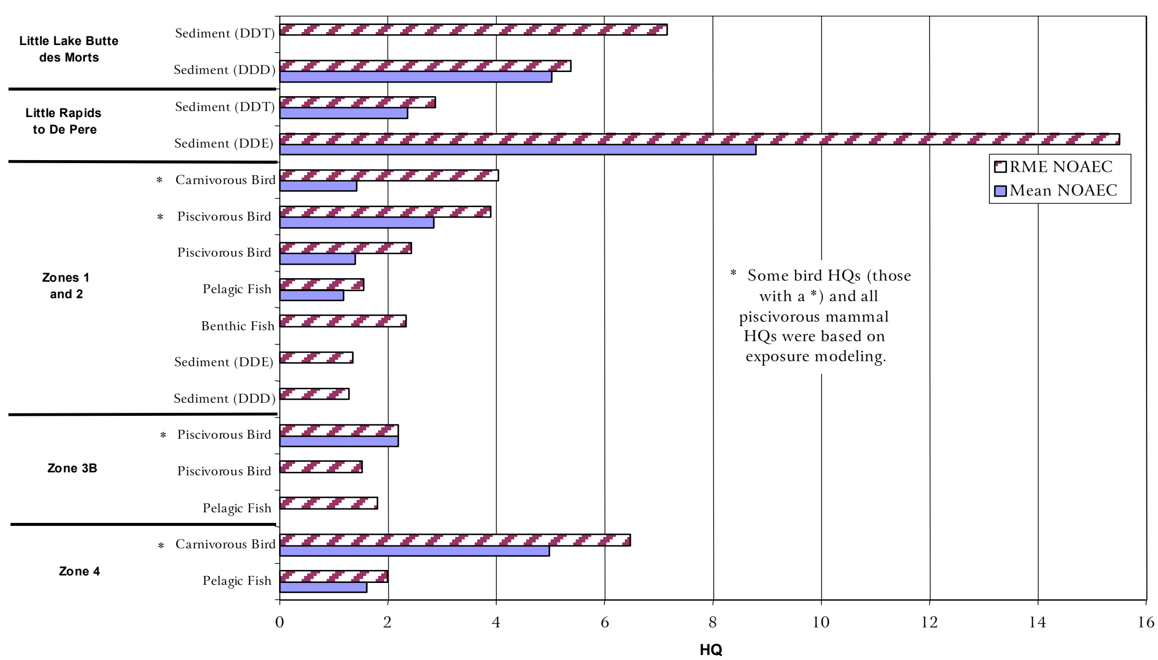
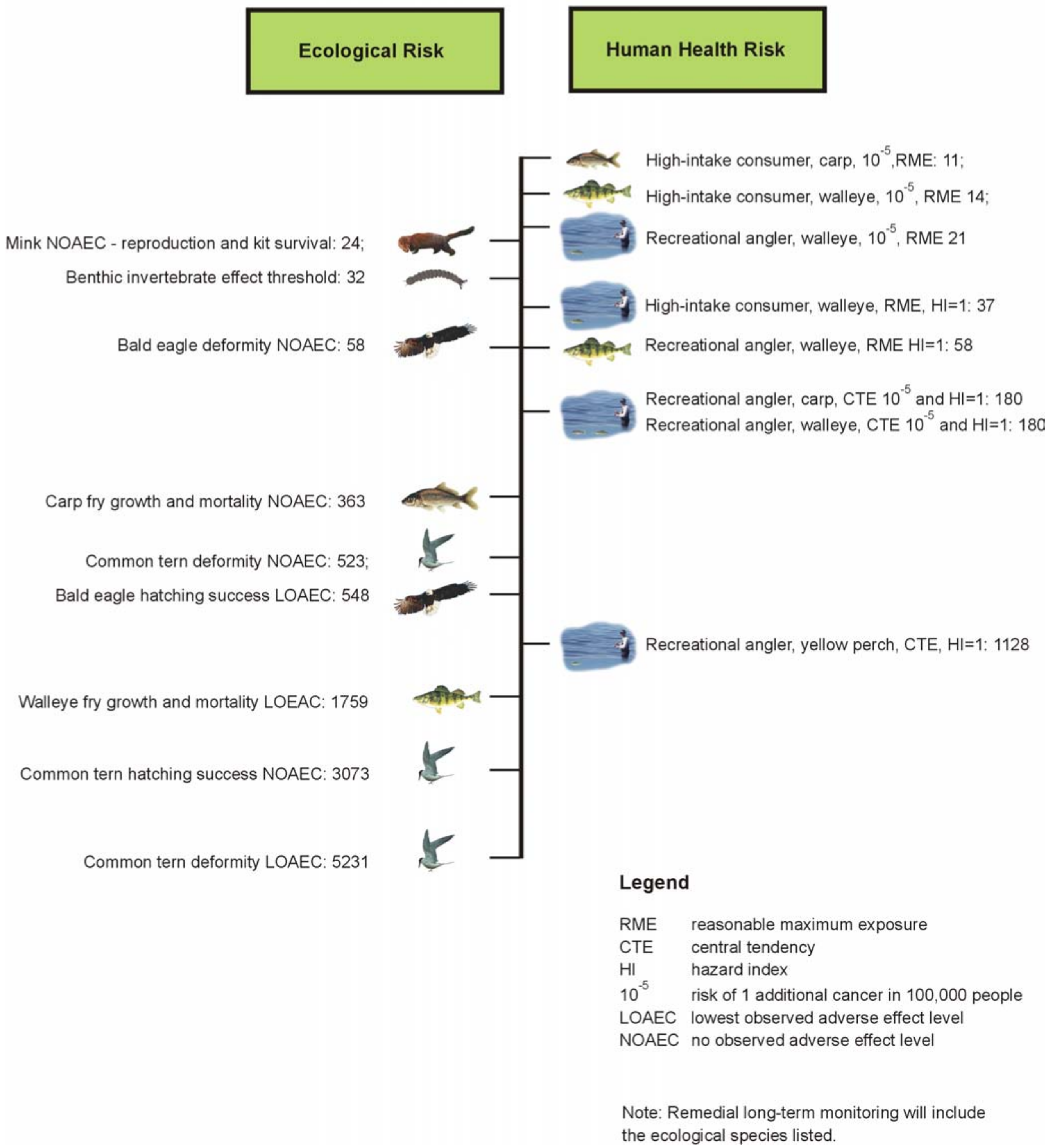


Figure 7. Summary of Sediment Quality Thresholds (SQTs - µg/kg)



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List of Appendices

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List of Acronyms

2,3,7,8-TCDD	2,3,7,8-tetrachloro-*p*-dibenzodioxin
2,3,7,8-TCDF	2,3,7,8-tetrachloro-*p*-dibenzofuran
95% UCL	95 percent upper confidence limit
˚C	degrees centigrade
˚F	degrees Fahrenheit
μg	microgram
μg/dl	micrograms per deciliter
μg/dl-blood	micrograms per deciliter of blood
μg/kg	micrograms per kilogram
μg/kg-BW/day	micrograms per kilogram of body weight per day
μg/kg-day	micrograms per kilogram per day
μg/kg-fillet	micrograms per kilogram of fish fillet
μg/kg-whole body	micrograms per kilogram of whole-body fish
μg/kg-sediment	micrograms per kilogram of sediment
μg/L	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
μg-PCB/kg-BW/day	micrograms of polychlorinated biphenyl per kilogram of body weight per day
μg-TCDD/kg-lipid	micrograms of 2,3,7,8-tetrachloro-*p*-dibenzodioxin per kilogram of lipid
μm	micrometer
ABS	ingestion absorption factor (fraction absorbed) or inhalation absorption factor (fraction absorbed)
AChE	acetylcholinesterase
ADD	average daily dose
AE	assimilation efficiency (in %)
AEHS	Association for the Environmental Health of Soils
AF	sediment adherence factor (in mg/cm^2)
$a_{f\text{-}wb}$	ratio of concentrations in fish fillet to concentrations in whole body of fish (in kg-fish/kg-fillets)
AHH	aryl hydrocarbon hydroxylase
Ah-R	aryl hydrocarbon receptor
AQUIRE	Aquatic Information Retrieval Database
ARCS	Assessment and Remediation of Contaminated Sediments
As^{3+}	arsenite (trivalent arsenic compound)
As^{5+}	arsenate
AT	averaging time (in days)
ATc	averaging time (carcinogenic)

List of Acronyms

ATnc	averaging time (non-carcinogenic) or averaging time for chronic, noncancer effects (in days)
$ATnc_C$	non-carcinogenic averaging time for a child
ATSDR	Agency for Toxic Substances and Disease Registry (part of the United States Public Health Service)
BAF	bioaccumulation factor
BLRA	baseline risk assessment
BLRPC	Bay Lake Regional Planning Commission
BMF	biomagnification factor
BSAF	biota-to-sediment accumulation factor
BTAG	Biological Technical Assistance Group
BW or *bw*	body weight (in kg)
BW_C	body weight for a child
C	chemical concentration (in mg/kg-soil or mg/L-water)
CA	concentration of chemical in air (in mg/m^3)
C_{ab}	chemical concentration in indoor air during a bath
C_{as}	chemical concentration in indoor air during a shower
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980 (the Superfund statute)
CF	conversion factor (in kg/g or kg/mg) or volumetric conversion factor (in L/1,000 cc)
Cfish	chemical concentration in fish (in mg/kg-fish)
$Cfish_{EPC}$	exposure point concentration in fish
$C_{fish\text{-}f}$	concentration of PCBs in fish fillet (in μg/kg-fillet)
$Cfish_{meas}$	measured fish chemical concentration
$Cfish_{measi}$	measured concentration of chemical *i* in fish (in mg/kg)
$C_{fish\text{-}wb}$	concentration of PCBs in whole body of fish (in μg/kg-whole body)
cfs	cubic feet per second
cm	centimeter
cm^2	square centimeter
cm^2/event	square centimeters per event
cm/hr	centimeters per hour
C_{oa}	chemical concentration in outdoor air

List of Acronyms

COC	chemical of concern
COPC	chemical of potential concern
C_{pw}	chemical concentration in sediment pore water
CR	contact rate or the amount of impacted medium contacted per event
CS	chemical concentration in sediment (in mg/kg-sediment)
C_{sed}	measured sediment chemical concentration
CSF	cancer slope factor
CSF_d	cancer slope factor for evaluating absorbed dermal doses (in $[\text{mg/kg-day}]^{-1}$)
CSF_i	inhalation cancer slope factor
CSF_o	cancer slope factor for evaluating administered ingestion doses (in $[\text{mg/kg-day}]^{-1}$)
CSFo	oral cancer slope factor (in $[\text{mg/kg-day}]^{-1}$)
C_{sw}	chemical concentration in surface water
$C_{sw\text{-}di}$	measured dissolved concentration for chemical *i* in water (in mg/L)
$C_{sw\text{-}ti}$	measured total concentration of chemical *i* in water (in mg/L)
CTE	central tendency exposure
CW	chemical concentration in water (in mg/L)
C_{wb}	chemical concentration in bath water
CWF	chemical concentration in waterfowl (in mg/kg-waterfowl)
CWF_{EPC}	exposure point concentration in waterfowl
CWF_{meas}	measured chemical concentration in waterfowl
CWF_{measi}	measured concentration of chemical *i* in waterfowl (in mg/kg)
C_{ws}	chemical concentration in shower water
C_x	concentration of the COPC in medium *x* (in mg/kg ww)
cy	cubic yard
days/yr	days per year
DDD	4,4'-dichlorodiphenyl dichloroethane (includes isomers o,p'-DDD and p,p'-DDD)
DDE	4,4'-dichlorodiphenyl dichloroethylene (includes isomers o,p'-DDE and p,p'-DDE)
DDOH-PA	metabolite of DDT conjugated to a fatty acid

List of Acronyms

DDT	4,4'-dichlorodiphenyl trichloroethane (includes isomers o,p'-DDT and p,p'-DDT)
DNA	deoxyribonucleic acid
D.O.	dissolved oxygen
dwt	dry weight
EC_{20}	20 percent effect concentration
EC_{30}	30 percent effect concentration
EC_{50}	50 percent effect concentration
ED	exposure duration (in years)
ED_C	exposure duration for a child
ED_T	estimated daily dose (in mg/kg-BW/day ww)
EEC	Exposure Effect Concentration or Extreme Effect Concentration
FRFood	Fox River Food Model
FRG	Fox River Group, which is composed of the following seven companies (listed alphabetically): Appleton Papers, Inc.,; Fort James Corporation; NCR Corporation; P. H. Glatfelter Company; Riverside Paper Corporation; U.S. Paper Mills Corporation; and Wisconsin Tissue Mills, Inc.
FS	feasibility study
g	gram
GAS	Graef, Anhalt, Schloemer and Associates, Inc.
GBFood	Green Bay Food Model
GBTOXe	Green Bay Toxics Model
g/day	grams per day
GE	gross energy (in kcal/g)
g-fish/day	grams of fish per day
GLEMEDS	Great Lakes Embryo Mortality, Edema, and Deformities Syndrome
GLWQI	Great Lakes Water Quality Initiative
g/meal	grams per meal
g/mole	grams per mole
g-waterfowl/day	grams of waterfowl per day
g/yr	grams per year
H^+	protons
HEAST	Health Effects Assessment Summary Table
Hg^0	elemental mercury
Hg^{2+}	mercuric ion

List of Acronyms

Hg_2^{2+}	mercurous ion
HgOH	inorganic mercury
HI	hazard index
Hi_i	hazard index for chemical *i*
HQ	hazard quotient
hrs/day	hours per day
I	chemical intake (in mg/kg-BW/day)
I_0	interpolated zeroed grid
I_d	interpolated deleted grid
I_{der-s}	absorbed dose from dermal contact with sediment (in mg/kg-BW/day)
I_{der-w}	absorbed intake from dermal contact with water (in mg/kg-BW/day) = $TBS \cdot FBE$
IEUBK	Integrated Exposure Biokinetic/Uptake Model
I_{ing-f}	intake from ingestion of fish (in mg/kg-BW/day)
I_{ing-s}	intake from incidental ingestion of sediment (in mg/kg-BW/day)
I_{ing-w}	intake from ingestion of water (in mg/kg-BW/day)
I_{ing-wf}	intake from ingestion of waterfowl (in mg/kg-BW/day)
I_{inhal}	intake from inhalation (in mg/kg-BW/day)
Inc	intake from ingestion of fish averaged over the exposure period (in mg/kg-day)
IntFacC	intake factor for cancer risk (in $[mg/kg]^{-1}$)
IntFacNC	intake factor for chronic, noncancer effects (in $[mg/kg]^{-1}$)
IPS	Integrated Paper Services
IR	ingestion rate (in g/day or L/day) or inhalation rate (in m^3/hour) or incidental sediment ingestion rate (in mg-sediment/day)
IR_A	ingestion rate for an adult
IR_C	ingestion rate for a child
IRIS	Integrated Risk Information System
IUPAC	International Union of Pure and Applied Chemistry
I_x	rate of ingestion of medium *x* (in mg/day or kg/day ww)
kcal/day	kilocalories per day
kcal/g	kilocalories per gram

List of Acronyms

kg	kilogram (1 kg is approximately equivalent to 2.2 pounds)
kg-fish/kg-fillets	kilograms of fish-to-kilograms of fillets
kg/g	kilograms per gram
kg/L	kilograms per liter
kg/mg	kilograms per milligram
km	kilometer (1 km is approximately equivalent to 0.6 mile)
km^2	square kilometer
km^3	cubic kilometer
K_{ow}	octanol-water partitioning coefficient
Kp	permeability coefficient
LADD	lifetime average daily dose
LC_{10}	10 percent lowest effect concentration
LC_{12}	12 percent lowest effect concentration
LC_{50}	50 percent lowest effect concentration
LC_{90}	90 percent lowest effect concentration
L/1,000 cc	liters per 1,000 cubic centimeters
LD_{10}	lethal dose to 10 percent of test population
LD_{20}	lethal dose to 20 percent of test population
LD_{30}	lethal dose to 30 percent of test population
LD_{50}	lethal dose to 50 percent of test population
L/day	liters per day
LLBdM	Little Lake Butte des Morts
L/m^3	liters per cubic meter
L/mg	liters per milligram
LOAEC	Lowest Observed Adverse Effect Concentration
LOAEL	Lowest Observed Adverse Effect Level
LOEL	Lowest Observed Effect Level
m^2	square meter
m^3	cubic meter
MDNR	Michigan Department of Natural Resources
ME	metabolizable energy (in kcal/g prey)
meals/yr	meals per year
MEC	Moderate Effect Concentration
MeHg	methylmercury (organic mercury)
MFO	mixed function oxidase
mg	milligram

List of Acronyms

mg-Aroclor 1254/kg-BW/day	milligrams of Aroclor 1254 per kilogram of body weight per day
mg/cm^2	milligrams per square centimeter
mg/day	milligrams per day
mg-Hg/kg-BW/day	milligrams of mercury per kilogram of body weight per day
mg/kg	milligrams per kilogram
mg/kg-BW	milligrams per kilogram of body weight
mg/kg-BW/day	milligrams per kilogram of body weight per day
mg/kg-day	milligrams per kilogram per day
mg/kg-DDE	milligrams per kilogram of 4,4'-dichlorodiphenyl dichloroethylene
mg/kg-DDT	milligrams per kilogram of 4,4'-dichlorodiphenyl trichloroethane
mg/kg-egg	milligrams per kilogram of egg
mg/kg-fish	milligrams per kilogram of fish
mg/kg-sediment	milligrams per kilogram of sediment
mg/kg-soil	milligrams per kilogram of soil
mg/kg-waterfowl	milligrams per kilogram of waterfowl
mg/L	milligrams per liter
mg/L-water	milligrams per liter of water
mg/m^3	milligrams per cubic meter
mg/mg	milligrams per milligram
mg-sediment/day	milligrams of sediment per day
mg/yr	milligrams per year
m^3/hr	cubic meters per hour
mi^2	square mile
mi^3	cubic mile
ml/day	milliliters per day
mm	millimeter
m^3/mg	cubic meters per milligram
MNFI	Michigan Natural Features Inventory
MRL	Minimal Risk Level
m/s	meters per second
m^3/s	cubic meters per second
MSA	Metropolitan Statistical Area
MT	metric ton
MW	molecular weight (in g/mole)
N	non-interpolated grid

List of Acronyms

NASS	National Agricultural Statistics Service
NAWQC	National Ambient Water Quality Criteria
NCP	National Contingency Plan
NCR	National Cash Register
"ND"	no data
NEC	No Effect Concentration
ng/kg	nanograms per kilogram
ng/kg-egg	nanograms per kilogram of egg
ng/kg-TCDD/egg	nanograms per kilogram of 2,3,7,8-tetrachloro-*p*-dibenzodioxin per egg
ng/kg-TEQ/egg	nanograms per kilogram of toxic equivalency per egg
ng/kg-ww/eagle	nanograms per kilogram of wet weight per eagle
ng/kg-ww/egg	nanograms per kilogram of wet weight per egg
ng/L	nanograms per liter
ng-TEQ/kg-ww/egg	nanograms of toxic equivalency per kilogram of wet weight per egg
NOAA	National Oceanic and Atmospheric Administration
NOAEC	No Observed Adverse Effect Concentration
NOAEL	No Observed Adverse Effect Level
NOEL	No Observed Effect Level
NRDA	Natural Resource Damage Assessment
N.W.R.	National Wildlife Refuge
OMOE	Ontario Ministry of the Environment
PAH	polynuclear aromatic hydrocarbon
PC	permeability constant (in cm/hr)
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PCH	planar chlorinated hydrocarbon
PCP	pentachlorophenol
pg	picogram
pg/g	picograms per gram
pg/kg-day	picograms per kilogram per day
PHH	planar halogenated hydrocarbons
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRP	potentially responsible party
QA	quality assurance

List of Acronyms

QA/QC	quality assurance/quality control
R	cancer risk
RA	risk assessment
$Ratio_{CAFI}$	child-to-adult fish ingestion ratio
RBFC	risk-based fish concentration
RBSC	risk-based screening concentration
$RBSC_{SA\text{-}fish}$	high-intake fish consumer risk-based screening concentration for carcinogenic or non-carcinogenic chemicals
RETEC	Remediation Technologies, Inc.
RF	reduction factor
RfC	EPA Reference Concentration
RfD	chronic oral reference dose (chemical-specific) or EPA Reference Dose
RfD_d	reference dose for evaluating absorbed dermal doses (in mg/kg-day)
RfD_o	reference dose for evaluating administered ingestion doses (in mg/kg-day)
RfDo	oral reference dose for chronic, noncancer effects (in mg/kg-day)
RF_{fish}	reduction factor for fish
RF_{fishi}	reduction factor for chemical *i* for fish (in mg/mg)
RF_{WF}	reduction factor for waterfowl
RF_{WFi}	reduction factor for chemical *i* for waterfowl (in mg/mg)
R_i	cancer risk for chemical *i*
RI	remedial investigation
RI/FS	remedial investigation and feasibility study
RME	reasonable maximum exposure
ROD	Record of Decision
SA	exposed skin surface area (in cm^2 or cm^2/event) = $TBS \cdot FBE$
SAIC	Science Applications International Corporation
SAV	submerged aquatic vegetation and/or floating vegetation
SCS	Soil Conservation Service
SEC	Sediment Effect Concentration
SF	oral cancer slope factor (chemical-specific)
SLRA	screening level risk assessment

List of Acronyms

SMDP	Scientific Management Decision Point
SMU	sediment management unit
SQC	Sediment Quality Criteria
SQT	sediment quality threshold
SVOC	semivolatile organic compound
SWAC	sediment-weighted average concentration
TBS	total body surface area (in cm^2)
TCDD	2,3,7,8-tetrachloro-*p*-dibenzodioxin
TCDD-Eq	2,3,7,8-tetrachloro-*p*-dibenzodioxin equivalent
TCDF	2,3,7,8-tetrachloro-*p*-dibenzofuran
TEC	Threshold Effect Concentration
TEF	toxic equivalency factor
TEL	Environmental Canada Threshold Effect Level
TEQ	toxic equivalency
TF_{bwa}	bath water-to-air transfer factor
Tf_{bwai}	transfer factor for chemical *i* for volatilization from bath water to air (in L/m^3)
TF_{sdpw}	sediment-to-pore water transfer factor
Tf_{sdpwi}	transfer factor for chemical *i* for sediment to pore water (in kg/L)
TF_{sh}	shower water-to-air transfer factor
Tf_{shi}	transfer factor for chemical *i* for volatilization from shower water to air (in L/m^3)
TF_{swoa}	surface water-to-air transfer factor
Tf_{swoai}	transfer factor for volatilization from surface water to outdoor air (in L/m^3)
THI	target hazard index
THQ	target hazard quotient
TIE	Toxicity Evaluation Identification
TOC	total organic carbon
TR	target risk
TRV	Toxicity Reference Value
TSS	total suspended solids
$UHIa1\text{-}inh\text{-}c_i$	unit hazard index for chemical *i* for inhalation of outdoor air by a young child (in m^3/mg)
$UHIa2\text{-}inh\text{-}c_i$	unit hazard index for chemical *i* for inhalation of outdoor air (in m^3/mg)
$UHIfd1\text{-}ing\text{-}c_i$	unit hazard index for chemical *i* for ingestion of waterfowl (in kg/mg)

List of Acronyms

*UHIfsh*1-*ing*-c_i	unit hazard index for chemical *i* for ingestion of fish (in kg/mg)
*UHIsd*1-*d*-c_i	unit hazard index for chemical *i* for dermal contact with sediment (in kg/mg)
*UHIsd*1-*ing*-c_i	unit hazard index factor for chemical *i* for ingestion of sediment (in kg/mg)
*UHIw*1*av*-*inh*-c_i	unit hazard index for chemical *i* for inhalation of indoor air by a young child (in m^3/mg)
*UHIw*1-*d*-c_i	unit hazard index for chemical *i* for dermal contact with surface water by a young child (in L/mg)
*UHIw*1-*ing*-c_i	unit hazard index for chemical *i* for incidental ingestion of surface water by a young child (in L/mg)
UHIw2av-*inh*-c_i	unit hazard index for chemical i for inhalation of indoor air by an adult (in m^3/mg)
UHIw2-*d*-c_i	unit hazard index for chemical *i* for dermal contact with surface water (in L/mg)
UHIw2-*ing*-c_i	unit hazard index for chemical *i* for incidental ingestion of surface water (in L/mg)
UHIw3-*d*-c_i	unit hazard index for chemical *i* for dermal contact with sediment pore water (in L/mg)
UP	Michigan's Upper Peninsula
URF	unit risk factor
*URFa*1-*inh*-c_i	unit risk factor for chemical *i* for inhalation of outdoor air by a young child (in m^3/mg)
*URFa*2-*inh*-c_i	unit risk factor for chemical *i* for inhalation of outdoor air (in m^3/mg)
*URFfd*1-*ing*-c_i	unit risk factor for chemical *i* for ingestion of waterfowl (in kg/mg)
*URFfsh*1-*ing*-c_i	unit risk factor for chemical *i* for ingestion of fish (in kg/mg)
URF_i	inhalation unit risk factor
*URFsd*1-*d*-c_i	unit risk factor for chemical *i* for dermal contact with sediment (in kg/mg)
*URFsd*1-*ing*-c_i	unit risk factor for chemical *i* for ingestion of sediment (in kg/mg)
*URFw*1*av*-*inh*-c_i	unit risk factor for chemical *i* for inhalation of indoor air by a young child (in m^3/mg)
*URFw*1-*d*-c_i	unit risk factor for chemical *i* for dermal contact with surface water by a young child (in L/mg)

List of Acronyms

URFw1-ing-c_i	unit risk factor for chemical *i* for incidental ingestion of surface water by a young child (in L/mg)
URFw2av-inh-c_i	unit risk factor for chemical *i* for inhalation of indoor air by an adult (in m^3/mg)
URFw2-d-c_i	unit risk factor for chemical *i* for dermal contact with surface water (in L/mg)
URFw2-ing-c_i	unit risk factor for chemical *i* for incidental ingestion of surface water (in L/mg)
URFw3-d-c_i	unit risk factor for chemical *i* for dermal contact with sediment pore water (in L/mg)
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UWSGI	University of Wisconsin Sea Grant Institute
W.A.	Wildlife Area
WDH	Wisconsin Department of Health and Social Services
WDNR	Wisconsin Department of Natural Resources
WHO	World Health Organization
wLFRM	Whole Lower Fox River Model
WSEV	Window Subsampling Empirical Variance
ww	wet weight
YOY	young-of-the-year